Increase accuracy of system operation of unloading heavy coal sinks and middlings in jigs

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S u m m a r y : The article presents a study on improving the accuracy work of measurement and adjustment of the height of the coal bed - one of the most important process parameters of coal cleaning in jigs. Were identified shortcomings of existing sensors. Were worked out the ways of improving these measuring devices. In article proposed a method to perform a qualitative assessment for the control system of accuracy of unloading heavy sinks and middlings in jigs.
K e y w o r d s : Jigging, coal bed, yield of fractions, density, lifting force.

INTRODUCTION

Method of hydraulic jigging of coal continues to be one of the most common methods of preparation of fine coal during recent decades. The total mass of fine coal reprocessing enriched by jigging is very impressive and makes up dozens of millions of tons despite a decline in the trend of reprocessing this type of coal in the early 2000's. But the quality of the processed product does not always satisfy consumers of coal [11].

In such a situation any appreciable increase in the yield of useful products enrichment and improvement of their quality is a significant contribution to improving the efficiency of the coal industry of the country. Such positive changes can be achieved only by improving the properties of automatic control systems (ACS) of coal bed regulation in jiggers.

In this regard the issue of increase the accuracy of unloading heavy sinks and middlings in jigs is an urgent task.

MATERIALS AND METHODS

Analysis of characteristics of technological equipment for the implementation of the process of jigging [1, 6, 8, 26] shows that the main characteristics of jigs ACS have been significantly improved over the last 20-30 years [12, 14,15].

In particular, have been developed and proposed for industrial use blocks of forced oscillations BVK (for the best choice of air-water cycle), have been developed various fuzzy controllers, corrective function blocks for the systems unloading heavy products of enrichment, appeared device for analyzing and forecasting of process results [3, 7, 10, 23]. However, the available information does not confirm the fact of significant improvement of products of jigging [24, 29, 30].

In this article, the authors set out to identify the main reason that prevents the growth of ACS efficiency of the process of coal beneficiation process in jigs and suggest ways to improve these systems.

At the first stage let's try to find the "weak link", which is one of the main reasons hindering for achievement the high quality products of coal enrichment in jigs.

At first let's analyze the control system of water-air regime of jigging machine.

In the works of N.Vinogradov, N.Shmachkov and E.Rafales Lamarcka [13, 17, 18, 22, 31] were shown that the speed of the rising stream of coal-water mixture during rippling determined the level of exfoliation of coal bed.

For quantifying the degree of exfoliation of the coal bed by fractions E. Rafales Lamarcka proposed criterion R, numerically equal to the expression:

$$R \cong n \int_{\text{cycle}} S\,dt, \tag{1}$$

where: R – loosening criterion, cm•c/min,

n – the number of oscillations of coal-water medium in 1 min,

S – moving of the upper layers of bed in a vertical direction, cm.

Subsequently in research work K.Vlasov and L.Lehtsier [32] were suggested to assess the value of loosening criterion R using a value S of lifting of certain layer of coal bed. Also was suggested to assess the value of loosening criterion R as the time of staying certain layer of coal bed in a movable state.

Thus after some transformations the expression (1) considering the above notation can be converted to the form:

$$R = \frac{2}{\pi} * \frac{t_s}{T} * S_{\max}. \tag{2}$$

From expression (2) we can see that in the first place the coal bed looseness is proportional to the relative duration of the moving condition of the coal bed and in the second place the coal bed looseness is proportional to the peak-to-peak value of height coal bed.

We'll note that numerous attempts to put into practice the conclusions that follow from the expression (2) do not allow fully getting a positive effect. Obstacle to the achievement of positive results was the difficulty of measuring the parameters t_s and S_{max}. This is explained by the following circumstances. Source of information for determining the value of loosening coal bed R is prismatic float sensor in all constructions of jiggers. The height of the float sensor to ensure stable movement in a coal-water mixture usually is chooses commensurate with the total height of the coal bed.

Significant part of the float sensor in the majority of jiggers is above the coal bed, and often overtop at 10-30 cm above the transport water. The lower part of float is usually located at a distance of 5-10 cm from the sieve of jigger. A typical form of such a sensor is shown in the figure below, which was taken from the work about coal preparation in jiggers [19]

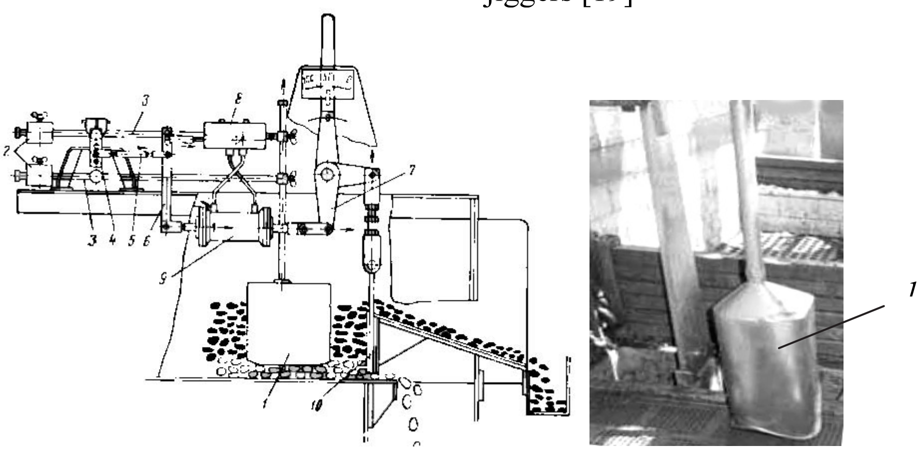

Fig. 1. Unloader of jig Humboldt and BATAC: 1 – float, 2 – counterweights, 3-7 – levers

Adjusting the position of the float sensor in the coal bed realized by the operator of jigger. Adjustment is made usually by plant or by removal the certain weight on the float or in a particular location of the lever system.

The exact method of determining the mass of loads for necessary adjustment does not exist, because there are no criterions for the accuracy testing of the settings. Jigs operators are trying to reconfigure float density when parameters of initial coal are changing. We can observe the similar situation looking at work of the system unloading heavy products of jigger enrichment.

RESULTS, DISCUSSION

Analyzing the mechanism and operation of various types of jiggers machines can be concluded that unloading process of heavy coal fractions depends only from the position of the float sensor regardless of the design of all jiggers.

The principle of process control by discharge is clear and simple: all the heavy fraction of the exfoliated coal bed located below the level of a certain fraction, you must discard (if this is the first or second branch of jigger during the incoming coal) or you must send it to a middling (if this is the last or penultimate branch of jigger). Coal-cleaning workers chosen usually medium density coal fraction 1,5-1,8 g/cm^3 as a certain coal fraction in separating zone which detaches the concentrate from rock**.** Let's note that just as in the case of automatic control system of water-air cycle, information for controlling unloading process heavy products goes from the same float sensor of coal bed height.

We have not discovered in published works research on the measurement accuracy of bed height with given density using the float sensor. Taking into account the above design features of float sensor, there is reason to assume that the signal carrying information about the height of a measurable layer bed can hardly be considered to be proportional to the true value of this height.

In considering this issue should be aware that the precise definition of a apparent coal-water mixture density is a complex task requiring the simultaneous use of hydrodynamic and probabilistic calculation methods, as well as accounting of the dimensions data of the float sensor and the jigger. In this connection, let's perform the assessment of the accuracy of measurement of height layer bed by approximate way for the purpose to obtain a qualitative picture of the dependence of the results of height measurement from the fractional composition of coal bed.

To simplify the problem, let's represent the float in the form of a right prism with the cross-sectional area equal to 1cm^2 and a height equal to the height of the coal bed.

Assume also that the float is immersed in the liquid whose density varies in height in the same relationship as the changing of density of the solids coal bed. This task may be, for example, been solved by means of a magnetic fluid in a magnetic field. The magnetic field strength along the height of the vessel with a magnetic fluid is formed accordingly to achieve the desired distribution of the viscosity of magnetic fluid along the height (development of Chemical Technology University named after DI Mendeleev) [14, 16, 20, 21].

Different viscosity of the magnetic fluid in the different layers of the vessel leads to surface of solid non-magnetic inclusions. And each of those particles occupies a position corresponding to the density of the layer of magnetic fluid.

In this hypothetical experiment on a float with prismatic cross-sectional area S_n, submersed in a vessel filled with a fluid of variable density height *h*, will act the buoyancy force *F,* equal to the value:

$$F = S_{\ddot{\imath}} \int_0^h \rho_h \, dh. \qquad (3)$$

Replacing the integral by sum with limits similar to the real fractional composition of washed coal and assuming $S_n = 1cm^2$, we obtain:

$$F = \sum_{i=1}^{n} \rho_i \, dh. \qquad (4)$$

To perform this virtual experiment fractional composition of initial coal was adopted from the source given in [5, 25, 27, 28]. Numerical data and graphic display of this fraction composition is shown in Table 1 and Fig. 2.

A graph given on Figure 2 shows the relationship between total yield fractions having a density greater than the density ρ_i and density ρ_i, constructed from the data in Table 1. A graph in Figure 3 shows the relationship between outputs of narrow fractions of initial coal from the density ρ_i constructed from the data same of Table 1.

Table 1. The relationship between the coal yield of fractions and their density

Fraction number i	Fraction density (g/cm^3) ρ_i	Reference fractional composition F=171,75	
		Yield of narrow fraction (%) γ_i	Yield of fractions (%) density of which is greater then the density ρ_i
1	1,15	0,6	99,4
2	1,25	11,9	87,5
3	1,35	35,5	52,0
4	1,45	9,5	42,5
5	1,55	4,5	38,0
6	1,65	2,0	36,0
7	1,75	3,0	33,0
8	1,85	1,5	31,5
9	1,95	3,5	28,0
10	2,05	3,0	25,0
11	2,15	1,0	24,0
12	2,25	5,0	19,0
13	2,35	3,0	16,0
14	2,45	3,0	13,0
15	2,55	1,0	12,0
16	2,65	4,0	8,0
17	2,75	5,4	2,6
18	2,85	2,6	0

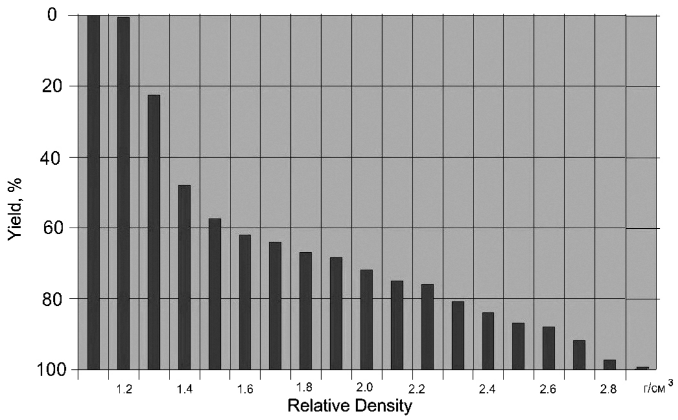

Fig. 2. Graph of the relationship between density ρ_i and total yield fractions having a density greater than the density ρ_i

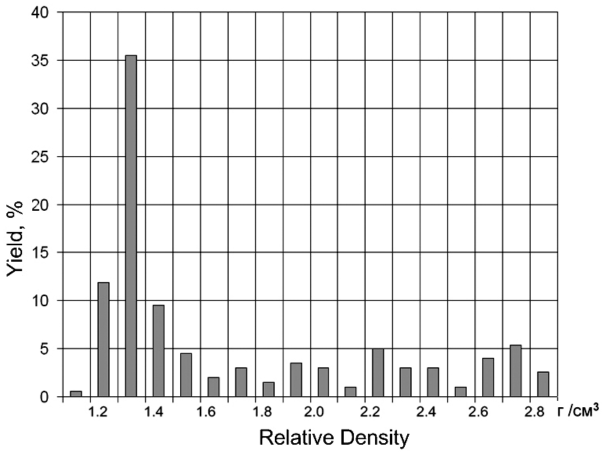

Fig. 3. Graph of the output of narrow fractions of initial coal

The graph in Figure 3 gives a visual representation of the contribution of each of the narrow coal fractions in the value of the elevating force of the float, calculated by formula (4).

According to Table 1, using the formula (4) let's calculate the elevating force of the float with $S_n = 1cm^2$ which located at an altitude of all coal fractions each of them numerically equal to their output. In this case, the elevating force F is equal to:

$$F = \sum_{i=1}^{18} \rho_i dh = 171{,}75\ g/cm^2 .$$

When the actual size of float sensor has the value Sn=300cm^2 and more, elevating force exceeds 50 kg. Such elevating force ensures a stable position of the float in pulsating mixture of coal and water.

Jigger operator executes separation of coal concentrate from middlings and rock at the height of the coal bed in which fractions density are equal 1.5-1.8 g/cm^3. Representativeness of the coal bed height measurement by given float sensor is defined as follows. We assume measuring is meaningful if the value of the buoyancy force acting on the float sensor placed in the coal bed may not be the same for different fractional compositions. Otherwise, such a measuring can not be considered to be meaningful, since for different heights of middle fractions sensor generates the same output signal.

Representativeness measure by float sensor of the height separating coal concentrate from the heavier fractions can be checked follows. An elevating force acts on a float which immersed in the coal bed.

To check the representativity the measured data of the height of the coal fractions, we must check whether exist another fractional composition of initial coal which provide the same elevating force for the float. To this end, a program was developed, generating Monte Carlo outputs of individual fractions according to equation of material balance and taking into account the patterns of distribution of output values. In these calculations the average values of output fractions remained unchanged. Block diagram of the program is shown in Fig. 4.

Studies have shown that equal elevating force (with honors to any small value, for example, such as 0.1%) can provide a variety of different combination of initial coal. Table 2 shows the two factional combinations obtained by calculation. For these combinations the value of elevating force *F* is the same (up to 0.1%) with a lifting force generated by the given fractional combination given in Table 1.

Let's note that despite the fact that two fractional cobinations of coal creates the same elevating force in the float sensor, the middle fractions are located at different heights of the coal layers in these two cases. For coal F = 171,65 g/cm^2 middle fractions located at a height of 10% higher (as judged by density) than those in the coal layers with a standard fractional composition. And for coal F=171,96 g/cm^2 middle fractions located at a height 5% lower than similar layers in the reference fractional composition.

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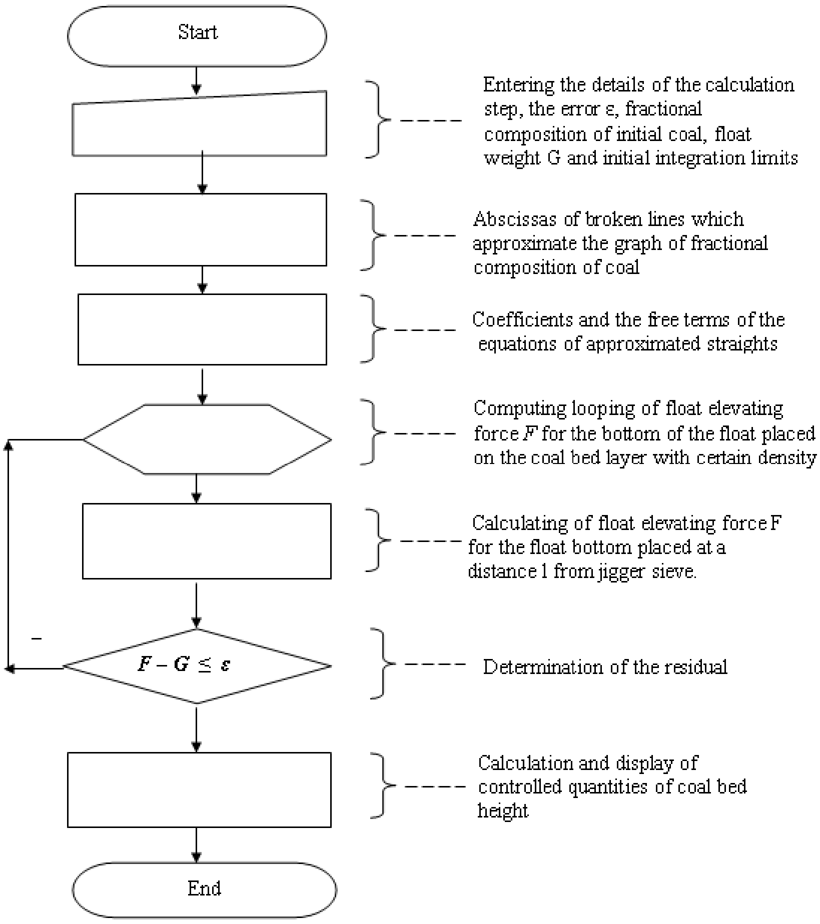

Fig. 4. Block diagram of calculating the density of the layer of coal bed measured by float sensor

Table 2. The relationship between density ρi and total yield of fractions which density is greater than the density ρ_i (for coals that create equal elevating force)

Fraction numberi	Fracitron density (g/cm^3) ρ_i	1-st fractional composition of coal $\sum_{\rho=1.15}^{\rho=2.85} \rho_i * \gamma_i = 171.65$		2-nd fractional composition of coal $\sum_{\rho=1.15}^{\rho=2.85} \rho_i * \gamma_i = 171.96$	
		Yield of narrow fraction (%)	Yield of fraction (%) density of which is greater then the density ρ_i	Yield of narrow fraction (%)	Yield of fraction (%) density of which is greater then the density ρ_i
1	2	3	4	5	6
1	2	3	4	5	6
1	1,15	0,6	99,4	3,6	96,4
2	1,25	6,9	92,5	25,2	71,2
3	1,35	40,5	52,0	11,9	59,3
4	1,45	14,5	37,5	8,3	51,0
5	1,55	4,5	33,0	4,5	46,5
6	1,65	2,0	31,0	2,0	44,5
7	1,75	3,0	28,0	3,0	41,5
8	1,85	2,0	26,0	6,5	35,0
9	1,95	1,0	25,0	5,7	29,3
10	2,05	1,5	23,5	4,4	24,9
11	2,15	1,0	22,5	4,0	20,9
12	2,25	1,0	21,5	6,0	14,9

1	2	3	4	5	6
13	2,35	1,5	20,0	2,2	12,7
14	2,45	2,0	18,0	3,0	9,7
15	2,55	1,0	17,0	2,0	7,7
16	2,65	4,0	13,0	4,0	3,7
17	2,75	6,4	6,6	3,1	0,6
18	2,85	6,6	0	0,6	0

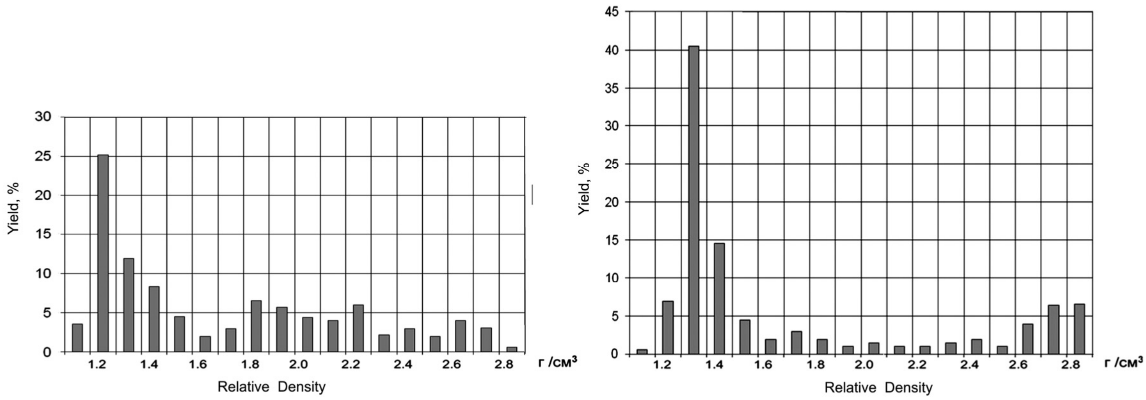

Fig. 5. Relationship between density ρ_i and total yield fractions that having density greater than the density ρ_i.
For the first graph, the force:
F = 171,65 g/cm^2, for the second F = 171,96 g/cm^2

Figure 4 shows the relationship between the yield of fractions and their density for computed combinations of initial coal.

Taking into account the average bulk density of fine coal fractions (0.5-13mm) we can be roughly assumed that the distance between identical layers of middle fractions obtained by calculation of fractional composition of coal is 10-12% of the total height of the coal bed, which in absolute terms is approximately 5-6 cm.

Graphs of the three fractional compositions are shown in Fig. 6. The graphs depict the dependence total output of enriched coal from the density of these fractions.

Let's look at the vertical line intersecting all three graphs. We can see that positions of middle fractions separating coal concentrate and heavy products enrichment correspond to different outputs.

In particular, the difference between the output of the reference fraction composition and outputs the calculated fraction compositions reaches 6.5%. This means that there may be a situation in which the float will not respond to changes in the height of the average coal fractions.

For further calculations to be on the safe side we'll take measurement error equal to 1%, that is more than 5 times smaller than the error from the graphs in Fig. 6.

Taking the average performance of jigger130 t / h and the duration of the jigger work 20 hours in a day, we can calculate the amount of process losses due to measurement error of height of the coal bed, due to changes in the fractional composition of initial coal.

Such losses in one working day (130 * 20 * 1 %) may be about 25 tons of fuel mass, sent to waste, or about the same amount of high- fractions that had to send to waste, but due to a sensor error were sent to the second compartment of jigger.

The presented method of research of presentability of the float sensor does not claim to high accuracy of the results. But the evidence and clarity of the results indicates that the qualities of coal beneficiation of processes ACS in jiggers are strongly influenced from the degree of reliability of the information coming from the float sensor of height bed.

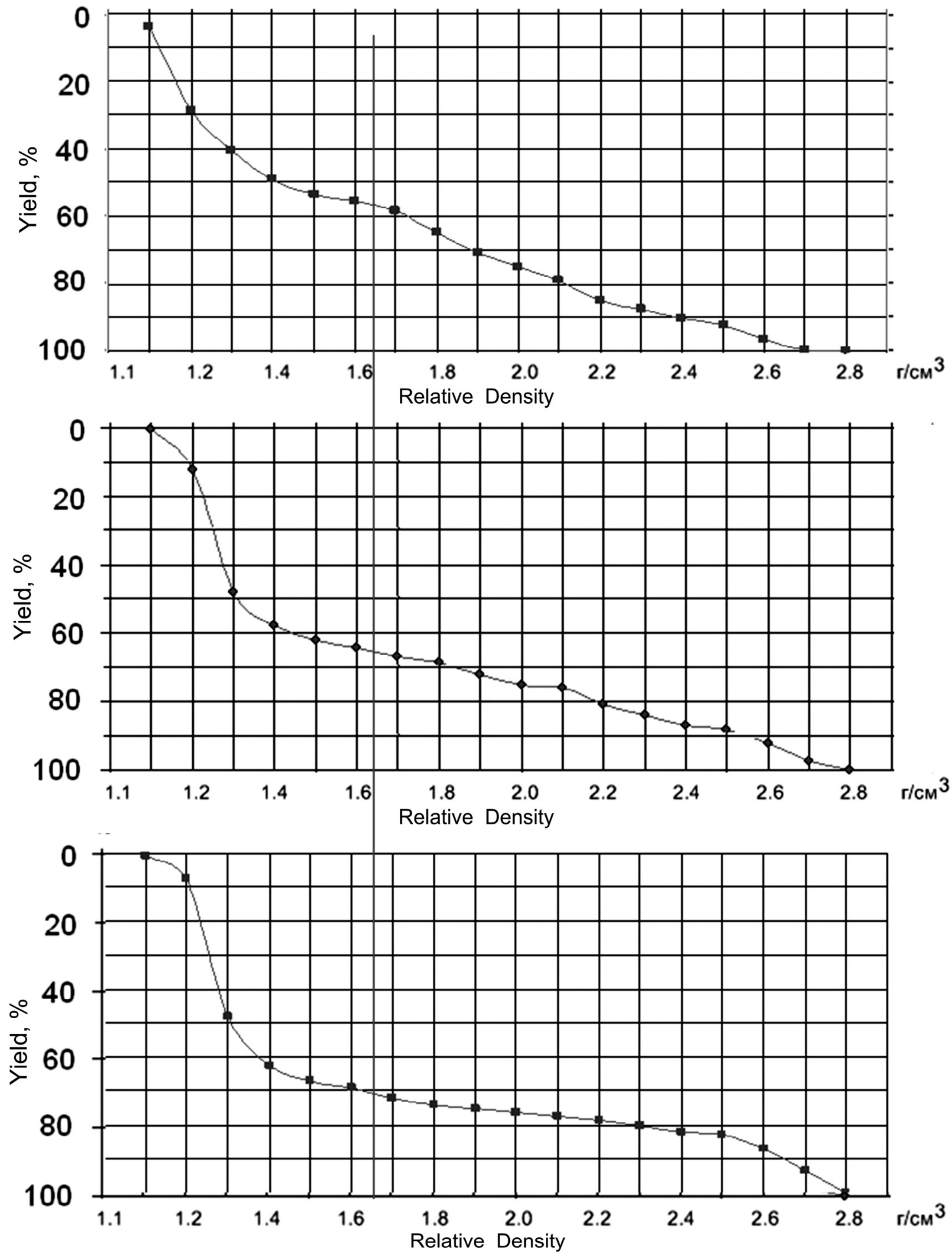

Fig. 6. Comparison disposition of the height of the various factions of the coals, which create equal lift when float switch is immersed in the coal bed

Indeed, if we assume that the output of float sensor signal is not showing the actual location of the narrow coal fractions in bed, then any regulator with any algorithms or corrective elements are not able to develop an effective control signal output value for successful control of jigger systems. At the same time, the graph in Figure 6, show that the effective use of coal bed height fractions sensor could successfully solve the problem of control of the parameters of jigger.

For the purpose of tracking the position of the certain layer can be applied float sensor, which checks only a certain fractions but not checks coal bed as a whole. Whether can such a hypothetical sensor provide effective tracking of position of coal bed fractions height which changes due to fluctuations of the coal characteristics? For this purpose we represent as coal bed height sensor prismatic float with $Sn=1cm^2$ and height about the height of the coal fractions with a density of 1.55-185 g/cm^3. With the help of data available in Tables 1 and 2, we construct dependence of elevating force of this float sensor from the density of bed layers in which sensor was sinking. Obtained the dependencies of the elevating force for two calculated fractional compositions are shown in Table 3.

The data shown the third and sixth columns of Table expressed the specific value of lifting force of the float (in g/cm^2) with a density of 1.65 g/cm^3 transported into layers of the coal bed of different density.

You may notice that the sign of the specific lifting force (i.e. the force action direction) is changing in the area of the average values of the height of the fractions of the coal bed. In this case information coming from such a sensor will allow to regulate the parameters of technological process of coal washing in jigs without disrupting process results.

CONCLUSIONS

1. Studies suggest that the automatic control of two major subsystems of coal washing in jigs: oscillatory process control system for delamination of coal bed by density and discharge control system of heavy fractions used as input information the signal for measuring from float sensor. Was shown that in some cases output of the float sensor do not reflect the actual state of monitored coal fractions. The cause of such errors is to change the fractional composition of initial coal. This can cause significant deviations of output process parameters from the specified values.

2. The occurrence of significant measurement errors of height bed layers can be due to an excessive big zone of control coal fractions. Proved that to improve the accuracy of jigs ACS the height of float sensor must be close to the average value of the height of the middle fractions of coal bed.

Table 3. The elevating force of float sensor that is configured to measure the average fractions of initial coal

Fractional composition of given coal F=171.75 g/cm^3			Fractional composition with altered location middle layer F=171.65 g/cm^3		
Number of the layer of the narrow fraction (from sieve),%	The average density of the bed layer, g/cm^3 , γ_i	The difference between the calculated density and density of medium fraction	Number of the layer of the narrow fraction (from sieve),%	The average density of the bed layer, g/cm^3 , γ_i	The difference between the calculated density and density of medium fraction
10	2,68	1,03	10	2,72	1,07
20	2,35	0,70	20	2,56	0,91
30	2,03	0,38	30	1,91	0,26
40	1,60	-0,05	40	1,47	-0,18
50	1,38	-0,27	50	1,35	-0,30
60	1,29	-0,36	60	1,28	-0,37
70	1,25	-0,40	70	1,25	-0,40
80	1,25	-0,40	80	1,25	-0,40
90	1,20	-0,45	90	1,25	-0,40
100	1,15	-0,50	100	1,18	-0,47

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ПОВЫШЕНИЕ ТОЧНОСТИ РАБОТЫ СИСТЕМЫ РАЗГРУЗКИ ПОРОДЫ И ПРОМПРОДУКТА В ОТСАДОЧНОЙ МАШИНЕ

Олег Лехциер

Аннотация. В статье представлены исследования по вопросу повышения точности работы измерения и регулировки высоты угольной постели - одного из самых важных параметров процесса обогащения угля в отсадочной машине. В статье выявлены недостатки существующих датчиков. Предложен путь совершенствования этих измерительных устройств. В статье предложен метод выполнения качественной оценки точности работы системы регулирования разгрузки породы и промпродукта в отсадочной машине.

Ключевые слова: отсадка, угольная постель, выход фракций, плотность, подъемная сила.